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GABBROS OF EAST SOOKE AND ROCKY POINT

by

H. C. Cooke

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Gabbros of East Sooke and Rocky Point.

By H. C. Cooke.

INTRODUCTION.

Two plutonic masses of general gabbroid composition occur on the southwestern coast of Vancouver island, about 15 miles southwest of the city of Victoria. The larger underlies the greater part of East Sooke peninsula and is elliptical in outline. Its major axis is about 5 miles in length and its minor axis about 2½ miles. It is of economic interest as it forms the country rock of the East Sooke copper deposits, and of scientific interest as it affords an excellent example of the course of differentiation of a gabbro magma. The smaller, or Rocky Point mass, lies about 3 miles to the east; it contains no ore deposits, and a much larger proportion of it is beneath sea-level, but in the variety and character of its rocks it is identical with the East Sooke body. A number of other masses of the same gabbro are found throughout the Sooke map-area, and in 1912 the generic name of "Sooke gabbro" was applied by Clapp[1] to the whole group. Clapp at that time also recognized and reported the prospective value of the copper deposits in East Sooke peninsula, and recommended a detailed examination of the district to secure more definite information as to its economic possibilities. Accordingly, early in the summer of 1913 the peninsula was mapped topographically by F. S. Falconer, of the Geological Survey staff, on a scale of 2,000 feet to 1 inch, with a 20-foot contour interval. Later in the season the writer and his assistants, V. Dolmage and A. McLeod, spent four weeks examining the geology of the two areas.

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[1] Geol. Surv., Can., Mem. 13, 1912, p. 113.

The writer wishes to express his thanks to C. H. Clapp for aid in the field and information freely supplied as to results obtained in the study of the other stocks of the Sooke gabbro which the writer was unable to examine; and to W. H. Collins and G. A. Young, of the Geological Survey staff, for many helpful suggestions and much critical discussion of this paper.

GENERAL GEOLOGY.

The principal formation of the peninsula is the Sooke gabbro. The nature of the mass, whether stock or laccolith, is unknown,[1] since bedding is difficult to determine in the basalt flows into which the gabbro is intrusive, and since the roof has been so completely removed that no foreign rock now occurs within the gabbro area, and the older basalts are present only in small, isolated patches along the shore.

The gabbro intrudes the Metchosin basalts of upper Eocene age,[2] and is, therefore, post-Eocene. It is overlain on Sooke peninsula by the Sooke formation, a series of slightly consolidated sandstones and conglomerates underlying a small area on the southeast coast and filling isolated wave-cut chasms on the south coast. These sediments were determined from their fossils to be of early Miocene age, or possibly middle or upper

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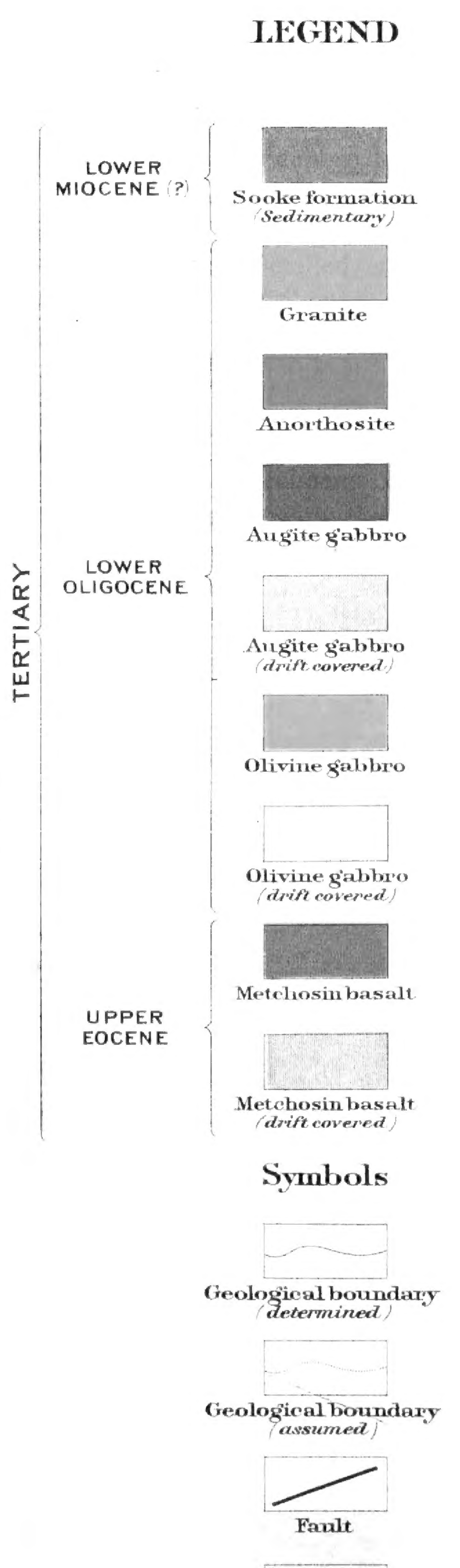
[1] A conjecture may be hazarded as to the nature of the intrusive masses from a knowledge of the amount of granitic differentiate present. F. E. Wright in his study of the gabbro mass of mount Bohemia (Mich. State Board Geol. Surv., Rept. 1908, p. 355) calculated from field evidence that the amount of aplitic differentiate was about 17 per cent of the whole mass. W. H. Collins has estimated that aplitic material formed approximately 12 per cent of the Gowganda diabase (Geol. Surv., Can., Mem. 33, p. 75). Clapp, when examining the Sooke gabbro masses, observed in the case of the Empress Mountain body, which has not been disturbed during consolidation, that the granitic differentiate formed a layer 100 feet thick at its summit. Assuming that this is the whole of the granitic differentiate, the gabbro is determined to have a maximum thickness of 800 feet, using Collins' figures. Assuming that segregations has been imperfect and that total amount of granitic differentiate is double that collected at the top; and in addition that in these gabbros the granite is only 5 per cent of the total mass instead of 12 per cent, the body is 4,000 feet thick as a maximum. The Empress Mountain mass is 6 miles long by 3 miles wide; its shape would, therefore, appear to be laccolithic rather than stock-like. Unfortunately none of the other masses in the Sooke map-area afforded data of this kind.

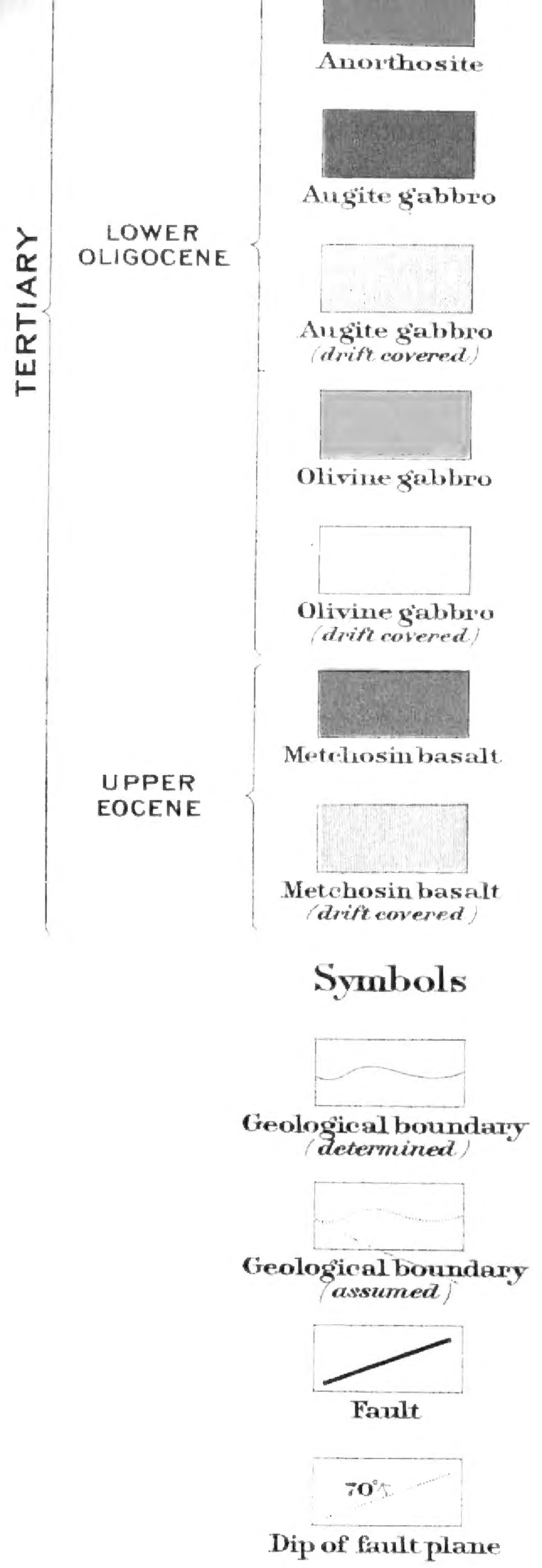
[2] Clapp, C. H., Geol. Surv., Can., Sum. Rept. 1912, p. 48.

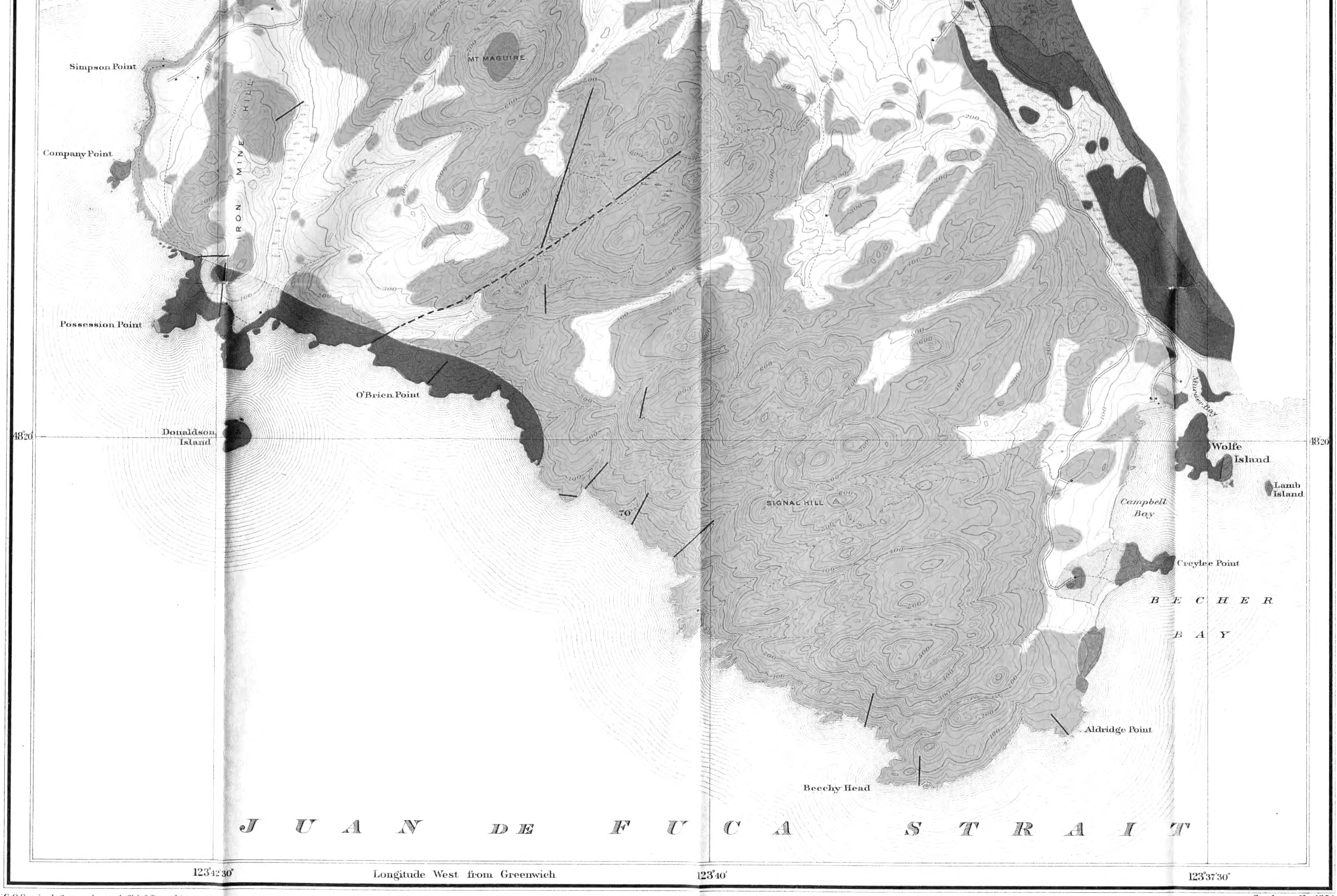
Canada
Department of Mines

HON. A. SEVIGNY, ACTING MINISTER; R.G. McCONNELL, DEPUTY MINISTER.

GEOLOGICAL SURVEY







C.O.Senécal, *Geographer and Chief Draughtsman.*
S.G.Alexander *and* A.S.Jost, *Draughtsmen.*

Catalogue No. 1654.

MAP 167 A
(Reissued 1917)

EAST SOOKE
VANCOUVER ISLAND
BRITISH COLUMBIA

Scale, 100 Miles to 1 Inch.

Scale, $\frac{1}{24,000}$

Feet
1000 0 2000 4000 6000

Metres
500 0 500 1000 1500

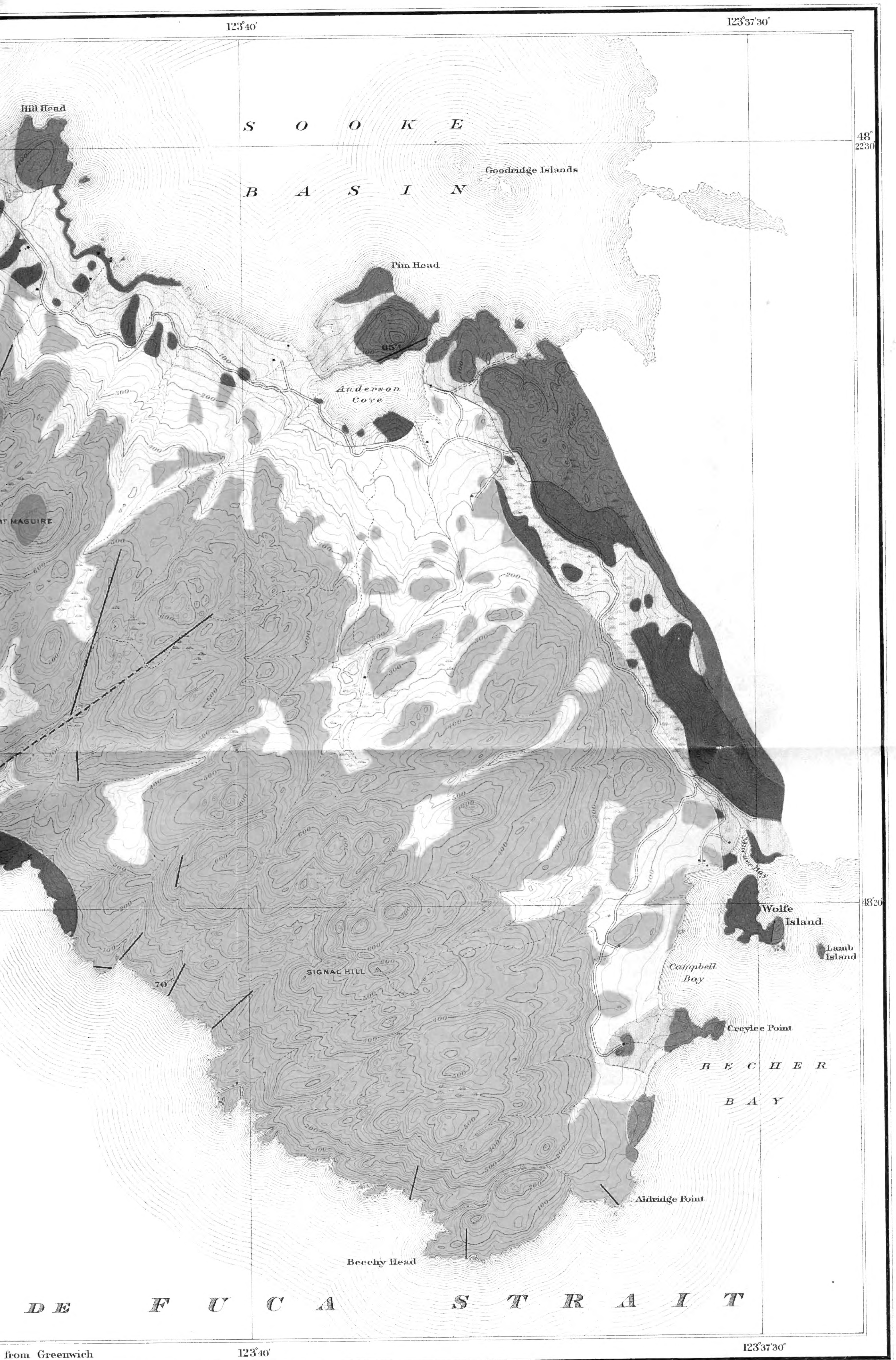
2000 FEET TO 1 INCH

GEOLOGY
H.C.COOKE. 1913.

TOPOGRAPHY
F.S.FALCONER, 1913.

To accompany Bulletin by H.C.Cooke

Department of Mines
A. Sevigny, Acting Minister; R.G. McConnell, Deputy Minister.
GEOLOGICAL SURVEY



Catalogue No. 1654

LEGEND

Culture

Roads and buildings

Roads (not well defined)

Trails

Schools

Post Offices

Shafts

Prospects

Wharves

Lighthouses

Triangulation stations

Water

Streams

Watercourses (with intermittent flow)

Fresh marshes

Tidal flats

Shore-line (position approximate)

Relief

Contours (showing land forms and elevations above sea level) Interval 20 feet

Sand beaches

Geographical position based on the latitude and longitude of U.S.C. and G.S. stations "Beechy Head" and "Island".

Approximate magnetic declination, 23° East.

MAP 167A
(Reissued 1917)

EAST SOOKE
VANCOUVER ISLAND
BRITISH COLUMBIA

Scale, $\frac{1}{24,000}$

1000 0 2000 4000 6000 Feet

Metres

GEOLOGY
H.C. COOKE. 1913.

TOPOGRAPHY
F.S. FALCONER. 1913.

Oligocene,[1] and the gabbro is, therefore, pre-Miocene, and possibly pre-middle Oligocene. A period of erosion at least moderately long must have ensued, after the intrusion of the gabbro and before the deposition of the Sooke formation, so that the age of the gabbro is probably lower Oligocene.

LITHOLOGICAL CHARACTERS AND MODE OF OCCURRENCE.

GENERAL DESCRIPTION.

Clapp[2] has described the principal rocks found in the East Sooke and Rocky Point masses. He distinguished hornblende, augite, olivine, and feldspathic gabbros, anorthosite and olivine anorthosite, pegmatite, aplite, and hornblendite. In addition he described a granite facies which he found in other bodies in the Sooke map-area, although not in those under discussion. Closer examination has revealed the presence of a small amount of this granite facies on Possession point, in the East Sooke peninsula, and on some of the islands near Rocky point, in the form of dykes.

The writer has grouped the rocks into four principal types: olivine gabbro, augite gabbro, anorthosite, and granite. The four principal types are, however, further differentiated into numerous sub-varieties, characterized by differences in texture, grain, and composition. Detailed study has shown that the various types and sub-varieties grade into one another, in some places gradually, and in other places rapidly. Olivine gabbro passes into augite gabbro by the decrease of the olivine content to zero, and either olivine or augite gabbro may pass into feldspathic gabbro or anorthosite by the decrease of both olivine and augite. Suites of specimens can be obtained to show all stages of these gradations, with the differences between the various

[1] Clapp, C. H., Geol. Surv., Can., Mem. 96, p. 335.
[2] Geol. Surv., Can., Mem. 13, 1912, pp. 113-119.

members of the series as minute as may be desired. The more acid types also form a series ranging from quartz diorite to very siliceous granite. They are intrusive into the gabbroid types, but this relation appears to be a local result of movements affecting the masses prior to complete solidification, since other bodies in the Sooke map-area not so affected contain similar acid types that grade downward into the gabbro.

A general regularity of arrangement exists between the four principal types. The olivine gabbro occupies the centre of the East Sooke mass, the augite gabbro and anorthosite are peripheral to it, and the single occurrence of granite lies at the extreme periphery. In the relations and arrangements of the sub-varieties great irregularity is found. This is summarized as follows:

Each sub-variety occurs in small, numerous, and irregular masses, that appear to possess no definite position within the body as a whole, but may outcrop at almost any point and in contact with any other sub-variety of the same principal type (i.e. olivine gabbro, augite gabbro, etc.) or of a different, but adjoining type.

At some points one sub-variety may grade quite gently into another, at others very rapidly.

Obscure and contradictory intrusive relations are frequently found between the various sub-varieties, and even between the broader types. At one place, for instance, a certain type, characterized by a definite composition and texture, may be observed to have a faintly chilled edge at its contact with another type, to send off intrusive stringers into it, and to include fragments of it; whereas at another point of contact between the same two types these relations are reversed.

The different varieties and sub-varieties are found associated in primary gneissic bands. Flow textures are also present in numerous places, particularly at the contacts between two varieties of rocks.

In consequence of these irregularities, the present surface of the gabbro mass is marked by widely varying textures and compositions, suddenly changing from one into another, and bewildering to the observer by reason of their number and the rapidity with which they succeed one another. Owing to this complexity, it is impossible to map the different types even on the large scale map that accompanies this report. An attempt has been made to indicate the positions of a few of the larger masses, but the boundaries of these are only approximate.

This rock complex is cut by a great number of dykes and igneous veins, which vary widely in composition. The earliest are of nearly the same composition as the normal gabbro, and are often porphyritic; a few of them contain olivine, but the majority do not. In the Rocky Point mass more acid types are found, younger than some at least of the gabbroid types. They approximate the granite in composition, and are supposed to represent part of the granitic differentiate of this magma. They are characterized by the presence of free quartz, sodic feldspars, hornblende, and titanite. These dykes, though often large, are never porphyritic. The dykes and older rocks are cut by a great number of replacement veins of all sizes, from a fraction of an inch in width up to 2 feet. These veins are composed of long-bladed hornblende crystals, without, as a rule other constituents than magnetite. Frequently large zones of hornblendite, up to 250 feet in width, are found. These do not appear, however, to have been formed by the deposition of hornblendite in a single large fissure, but rather by the ascent of solutions through a multitude of closely spaced slip planes of a large shear zone, with consequent thorough and rapid alteration of a large mass of country rock.

Still younger than these hornblendite veins, and cutting them, are large numbers of aplite veins. They are always of small size, rarely over an inch in width, and form both replacement veins and true fissure fillings. They are composed of quartz and albite or oligoclase-albite, with very little ferromagnesian minerals.

DETAILED DESCRIPTIONS.

Olivine Gabbro.

The olivine gabbro, which forms approximately 85 to 90 per cent of the exposed part of the intrusive mass, is a dark grey, greenish, or black rock, composed of plagioclase, augite, and olivine, with accessory ilmenite. The colour of the rock varies with that of the plagioclase, which ranges from pure white and greenish tints to purplish-black. When the feldspar is purplish black, it may easily be mistaken in the hand specimen, unless closely examined, for a ferromagnesian mineral, and the rock may be classified as augitite or hornblendite. The composition of the feldspar varies from pure anorthite to $Ab_{40}An_{60}$, but in the great majority of cases it is bytownite, $Ab_{15}An_{25}$ to $Ab_{25}An_{75}$.[1] The augite is almost colourless and non-pleochroic; it is probably low in iron, and approaches diallage in composition. Partial alteration to hornblende has taken place, and the cleavage faces of the latter are so conspicuous in the hand specimen as to give the impression in the field that the gabbro is chiefly hornblendic. No primary hornblende was found, however, in the thin sections. The olivine is also colourless, generally without much serpentinous alteration. Its axial angle varies about 90 degrees, so that some crystals are found to be optically positive, others in the same section optically negative. Such a behaviour, according to Rosenbusch, indicates an Fe0 content of about 12 per cent.

The proportions of the different constituents in the average olivine gabbro are 45 to 50 per cent of feldspar by volume, about the same amount of augite, 5 per cent of olivine, and 1 per cent of ilmenite. Wide variations from these proportions are found, however. Feldspar may be present in any proportion from 35 to 100 per cent; pyroxene from 0 to 65 per cent, olivine from 0 to 25 per cent. The variations, moreover, are fairly independent;

[1] The composition of the feldspar in these rocks was carefully determined from extinction angles given by the albite twinning lamellæ on the (001) face. To obtain these values with certainty, 5-10 grams of each rock specimen were crushed, sifted, washed, and examined for suitable cleavage flakes. All fragments were rejected in which the readings of the one set of extinction angles did not correspond within 2 degrees with those of the complementary set.

thus from a type made up of 60 per cent feldspar, 15 per cent pyroxene, and 25 per cent olivine, the rock may pass, without change in pyroxene content, through types with decreasing olivine and increasing feldspar, into a rock with 85 per cent feldspar and little or no olivine; or with constant olivine content, by decrease of feldspar and increase of augite, into a basic type carrying not more than 40 per cent feldspar with 35 per cent pyroxene; or the olivine content may become small or zero, and augite gabbros result, varying all the way from anorthosites 100 per cent feldspar to basic types with 60 per cent of pyroxene. Singularly enough, the composition of the individual minerals remain uniform, or approximately so, during these variations in proportion. A single example may be cited. On Bentinck island, south of Rocky point, four parallel gneissic bands of gabbro occur. The proportion of feldspar varies from about 50 per cent in the most basic band to about 90 per cent in the most feldspathic, but its composition in all four bands is $Ab_{20}An_{80}$.

The common olivine gabbro is equigranular, with an average grain of 1 to 2 mm. The feldspar in it tends to form squarish or rectangular crystals whose length is rarely more than twice the breadth. The augite is interstitial to the feldspar, and of much the same general shape. Three types varying from the normal texture are found frequently enough to be worthy of separate description.

Type A, termed pegmatite in the field because of its coarse grain, possesses the same equigranular texture and mineral composition as the common olivine gabbro, but the component minerals attain a diameter of 4 to 5 mm. on the average. In addition, the feldspars as a rule are zonally banded. Another, less common, and much more coarsely crystalline rock which may be classed with these " pegmatites " is occasionally found in rounded masses 6 feet or more in diameter included in rock of ordinary grain, into which it grades rapidly. In these masses the average grain approximates 15 to 25 mm.

Type B is a rock of ordinary grain, but is characterized by rather long prisms of augite and long laths of feldspar. The feldspar is usually very white, the augite more diopsidic in appearance than ordinarily. In some varieties there exists a sub-parallel arrangement between the feldspars and the augites, which gives the rock a peculiar and conspicuous columnar texture, but in others this is absent and the two minerals form an interlacing network.

Type C is characterized by the occurrence of the augite in large crystals and crystal aggregates, which enclose the feldspars poikilitically. These clumps of ferromagnesian mineral are more resistant to erosion than the surrounding more feldspathic parts, so that the weathered surface acquires an uncommon, embossed appearance. In one variety the clumps of ferromagnesian mineral have an average diameter of 4 to 5 mm., in a second variety of from 2 to 3 cm.

Augite Gabbro.

The augite gabbro contains no olivine, but is otherwise identical, macroscopically and microscopically, with the normal olivine gabbro. The unusual columnar texture, type B, that distinguishes some of the varieties of olivine gabbro, was not found in any of the augite gabbros; but otherwise most of the variations in grain and composition found in the one can be duplicated in the other. The composition of the constituent minerals is also much the same in both. Most of the feldspar is bytownite, near $Ab_{20}An_{80}$, but whereas in the olivine gabbros the range of composition extends only to $Ab_{40}An_{60}$, in the augite gabbros it attains $Ab_{60}An_{40}$. The augite, so far as could be determined by microscopic means, is the same in both rocks.

Gneissic Phases.

Both the olivine and augite gabbros frequently assume gneissic structures and textures. These may be found here and there over the whole surface of the intrusive, but are much more numerous near the periphery than towards the centre. Altogether, gneissic rocks may form 2 or 3 per cent of the whole surface. The most common structure of this sort is primary gneissic banding, in which gabbros of widely differing grain and composition are arranged in long parallel ribbons or bands. These bands vary from 1 to 6 feet in thickness; the contacts between them are always gradational, but the gradation always very rapid, usually not over an inch or two in width. The gabbros composing these bands are fresh and unsheared; they occasionally are characterized by flow textures arranged parallel to the long axis of the band. The grain of the different bands may vary from rather fine (average 1 mm. or less) to quite coarse (average 4 or 5 mm.); the composition, from a rather basic olivine gabbro with perhaps 60 per cent of ferromagnesian mineral to a highly feldspathic gabbro almost anorthosite. The composition of the feldspar, however, rarely varies from one band to another.

Flow textures are also frequently found in these rocks. They occur at times, as mentioned, in the bands of primary gneiss just described; they may be observed occasionally in one variety of rock at its contact with another; although in some places near the periphery of the intrusive they affect the whole rock mass. They are always of the same type. The pyroxene forms narrow laths or needles which have been arranged with their long axes parallel to one another and at the same time a certain amount of parallelism of the feldspars has also been induced.

Anorthosites.

The anorthosites consist usually of bytownite, $Ab_{20}An_{80}$, with less than 5 per cent of ferromagnesian constituents. They are equigranular and medium to coarse-grained, with an average grain of 2·3 mm. They are chiefly remarkable on account of their manner of occurrence in small isolated masses. A few large masses are found in the East Sooke body, one, several hundred feet long, on the top of mount Maguire, a smaller one on the east shore of the peninsula, near Beechey head, a third on the west coast; but large masses are uncommon and are apt to contain in places considerable quantities of pyroxene and olivine. The remainder of the anorthosite is scattered throughout the gabbro in small, rounded lumps, 6 inches to a foot in diameter, which grade rapidly into the gabbro. The impression gained from field observation was that these feldspathic patches were apophysal in their nature, produced by the action of aplitic solutions on the normal gabbro. However, under the microscope it is clearly seen that the feldspar is highly calcic, instead of sodic as might be expected under the latter hypothesis, and the component minerals show no sign of being other than primary crystallizations, so the conclusion is inevitable that these bodies are really small segregations of anorthosite which were in process of separation from the molten magma when solidification took place.

Granite.

Granite is relatively very small in amount, and, as mentioned, is found only on Possession point, at the southwest corner of the peninsula. The main mass lies almost horizontal, with a low dip to the north, and is some 30 feet in thickness. It is very clearly intrusive into the complex of gabbro and Metchosin basalt that occurs here, which is penetrated and brecciated by long strings of granite.

The granite is a light, greenish-white rock, weathering to a brownish-white, with an average grain of less than 1 mm. It is composed of approximately 20 per cent quartz, 70 per cent oligoclase feldspar, $Ab_{85}An_{15}$, 6 per cent hornblende, and accessory amounts of magnetite and titanite. Many of the feldspars show zonal banding.

Dykes.

As already mentioned, the dykes are of two main types, gabbroid and granitic, although there are many sub-types, due to minor variations of composition and texture. The dykes usually have wide chilled edges, indicating that the gabbros into which they were intruded had become fairly cold.

The gabbroid dykes may be subdivided into the porphyritic and non-porphyritic types. The latter are of a basaltic composition, equigranular, and basaltic to gabbroid in texture according to size, and almost identical in composition so far as can be determined microscopically, with the gabbro which they cut. They are composed of 45 to 55 per cent bytownite, varying in different specimens from $Ab_{15}An_{85}$ to $Ab_{40}An_{60}$, but averaging about $Ab_{20}An_{80}$. The only other essential mineral is a colourless augite, but olivine is almost constantly accessory. The porphyritic dykes vary somewhat from the non-porphyritic, both in composition and texture. They are distinguished by the presence of phenocrysts of feldspar which, in a dyke 6 feet or more in width, may attain a diameter of ½ to 1 inch. These phenocrysts were invariably developed in place, as they do not appear in the chilled edge of the dyke for a distance of an inch or two from the margin, and from this point inward they become progressively larger until their full size is reached about 2 feet from the border. So far as could be determined, the composition of the phenocrysts was approximately that of the feldspar of the groundmass, although in some of the sections they were zoned.[1] The feldspar is uniformly a bytownite, about $Ab_{15}An_{85}$, as in the non-porphyritic dykes, and is present in approximately the same proportion, 45 to 55 per cent. The ferromagnesian mineral is the usual colourless augite, frequently altered to a greenish amphibole, but, unlike the non-porphyritic dykes, olivine was not identified.

The granite dykes, although few in number, form a fairly complete series, characterized by the presence of free quartz, in amounts varying from 2 to 3 per cent in the most basic, to 35 per cent in the most siliceous. The nature of the feldspar varies with the quartz content; in the dykes low in quartz the feldspar is andesine, $Ab_{60}An_{40}$, and as the proportion of quartz increases, the feldspar becomes progressively more sodic until in the most acid it becomes $Ab_{90}An_{10}$. The ferromagnesian mineral undergoes a corresponding change. In the basic types a little pyroxene may be present, but hornblende predominates in all; a small amount of biotite, up to 4 or 5 per cent, is always

[1] One case was observed in which the outer zones of the feldspar phenocrysts were more calcic than the inner.

present, indicating that water was being concentrated in these acid magmas, but not necessarily in large amount. The total ferromagnesian mineral may amount to 40 or 45 per cent in the more basic types, but rapidly decreases with increasing acidity, until in the very siliceous dykes there is less than 5 per cent. Titanium, which in the ordinary gabbros is always combined with iron as titaniferous magnetite, in the granite dykes always takes the form of titanite. Only five of the granite dykes were found, confined to the Rocky Point mass. This fact, coupled with the petrographic resemblance to the granites of East Sooke and other bodies, strongly suggests that the dykes are the granitic differentiate which in this mass has been forced into more definitely intrusive relations with the gabbro than in the other bodies.

The sequence of irruption of the dykes has not been determined satisfactorily owing to lack of sufficient data. Only in two cases were dykes observed to cut one another. On Bentinck island a dyke of the granitic type cuts one of the non-porphyritic gabbroid type. On Possession point a dyke of the porphyritic gabbroid type cuts the intrusive granitic differentiate. Assuming the equivalence of the granite of Possession point with the granite dykes of Rocky point, the sequence is as follows:

Porphyritic gabbroid dykes
Granite and granitic dykes
Non-porphyritic gabbroid dykes
Olivine and augite gabbros.

Veins.

Hornblendite Veins. The hornblendite veins are replacement veins formed by the action on the gabbro of solutions rich in iron and magnesia rising through joint cracks and other fissures. The majority of the veins are only a few inches in width, but some are very large, 50 to 250 feet wide. Like most replacement veins, they are characterized by great variability in width along their strike, and have no clean and definite vein wall, but grade into the unaltered wall rock. Under the microscope, the replacement of the various constituents of the wall rock by hornblende can be observed in all its stages. When it is complete, nothing but a felted mass of long-bladed crystals of dark green, common hornblende, or pargasite, remains. A very small amount of feldspar in minute interstitial grains is usually present, but it is doubtful whether it has been deposited from the solutions or is simply residual. The middle of the small veinlets is usually occupied by a string of magnetite grains with some pyrrhotite.

The very large hornblendite zones are identical with the smaller in composition, but differ from them in two important respects. They have been affected by faulting movements, and the copper ores have been deposited within them. The faulting had granulated the large-bladed hornblende crystals, so that much of the hornblende of these zones is now no more than cemented dust, and has produced numerous slickensided cracks and fissures, while at the same time much of the hornblende has been converted into chlorite. The solutions which carried the copper appear to have ascended through these fissures and deposited chalcopyrite and small amounts of calcite, quartz, pyrite, and zeolites.

The mode of formation of these wide hornblendite zones is a matter of some doubt. It seems impossible that alteration could have extended to such distances from the walls of a single narrow fissure, since in all the unfaulted hornblendite veins such alteration may be observed to extend only a few inches from the central joint crack. It seems equally unlikely that these zones could originally have been wide, open fissures, since, as will be next described, fissures originally only 2 or 3 feet in width, have been filled, not with solid hornblendite, but with coarse gabbro, grading into aplite at the centre. The most probable hypothesis appears to be, that these zones represent preexistent, sheeted fault zones which afforded the solutions a multitude of closely spaced planes of slip through which to rise, and thus gave them power to alter broad bands of country rock.

Gabbro-aplite Veins. Three or four veins, 1 to 3 feet in width, which can be described only as gabbro-aplite veins, were found during the course of the field work. One of these was observed on Bentinck island, a second and third on the Race rocks by the writer, and the fourth was found by his assistant, V. Dolmage, in the interior of East Sooke peninsula. These veins are characterized in three of the cases observed by a very basic edge, the width of which is about one-third that of the whole vein, grading into an aplitic centre. The composition of the edge in each case is that of a very coarse-grained basic gabbro: 60 to 75 per cent of pyroxene approximately, the remainder bytownite feldspar. From edge to centre a gradual decrease in the proportion of pyroxene takes place, with increase in the proportion and alkalinity of the feldspar, until near the centre the pyroxene alters to hornblende and becomes small in quantity, quartz begins to crystallize out, and the feldspar becomes oligoclase-albite, about $Ab_{90}An_{10}$. The whole of the Bentinck Island vein is exceedingly coarse-grained and many of the crystals are more than an inch in diameter. The change from a basic edge to an aplitic centre is not nearly so marked as in the other veins, but nevertheless the change in composition is seen under the microscope to have been similar. The ferromagnesian mineral is hornblende, which may be primary or secondary; the feldspars are zonally banded, with a kernel of composition $Ab_{30}An_{70}$, and outermost bands $Ab_{85}An_{15}$; and, as the last product of crystallization, some 5 per cent of quartz has been deposited in interstitial spaces.

Aplite Veins. The aplites are found both as fissure fillings and as replacement veins and apophyses. The fissure fillings are rarely more than an inch or two in width, and commonly only a fraction of an inch, with clean-cut walls very slightly altered by the solutions. The alteration of the gabbro has been much more intense where the aplitic solutions have been forced through minute cracks and the intermineral spaces, instead of into open fissures.

The aplite of the veins is equigranular, with an average grain of less than 1 mm., and is nearly pure white in colour. Free quartz is always present, and has been observed to constitute as much as 60 per cent of the total mass, and proportions of 35 to 40 per cent are common. Very sodic feldspar, about $Ab_{85}An_{15}$, often graphically intergrown with the quartz, is the other principal component; and the ferromagnesian elements are represented by a few shreds, rarely amounting to more than 2 or 3 per cent, of hornblende, chlorite, or mica. A little titanite is commonly present. The quartz is usually concentrated towards the centre of the veins, and occasionally the centre of a vein or apophysis is composed almost wholly of it.

Aplite replacements generally take the form of rounded apophyses rather than veins. They are not nearly so numerous as the aplite veins or the hornblendite replacements, but numerous enough to show that the aplitic solutions attack and alter the gabbro when forced into intimate contact with it. The tendency of the alteration is to convert the gabbro into aplite of the vein type. Under the microscope the augite of the gabbro is seen to have been changed to hornblende and biotite, calcic feldspar to more sodic, and ilmenite to titanite and magnetite; and quartz has been deposited in intermineral spaces.

The aplites are younger than all the rocks previously described, as they cut them all indifferently. They are probably older than the copper ores and the faulting which preceded the deposition of the latter. The evidence on these points is, however, largely inferential and may be summarized as follows:

No copper ores or ore minerals of any kind, with the exception of occasional grains of magnetite, have been found in any aplite vein.

Aplites are everywhere found cutting the hornblendite veins, except the large hornblendite zones which were faulted before ore deposition took place. Whitish fragments of sodic feldspar are fairly common in these big zones. The probability seems strong that the aplite veinlets must once have cut them also, but were destroyed by the later faulting, and that the feldspar fragments are all that now remain.

Ore veins are generally a later product of differentiation than igneous veins.

Relations to the Gabbro. That the aplites and hornblendites are genetically connected with the gabbro, and are pegmatitic vein deposits formed as the last exhalations of the cooling magma, is clearly shown by their internal and external relations. They cut all varieties of rocks found in the stocks, including the later dykes, and in the case of the aplites frequently fill well-defined fissures; hence they must not only be younger than all the other rocks, but must have been intruded after the complete solidification of all. Their mineralogy, especially that of the later, aplitic veins, is that of a pegmatite, i.e., a rock deposited from a magma highly charged with water and other volatile constituents. In occurrence they are entirely confined to the gabbro bodies, and rarely extend beyond their edges for even a few feet; so that they must have originated within it and probably at some depth.

Changes of Composition During Hornblendization and Aplitization. To determine the effects of the hornblendizing and aplitizing solutions on the gabbro, and at the same time arrive at the composition of the solutions which produced them, chemical analyses were made by M. F. Connor of a typical olivine gabbro, a hornblendite, and an aplite. The results of the analyses, given below, were then plotted on the straight-line diagram described by Mead[1] in which the points on the curves are determined by dividing the percentage of each oxide in the fresh rock —in this case the gabbro—by its percentage in the altered rock —the hornblendite and aplite respectively. The results (Figure 1) of the hornblendic alteration are shown by the solid line, the aplitic alteration by the broken line. They are discussed in detail in another part of the bulletin.

The straight line diagram (Figure 1) is a convenient means of expressing graphically the character of the changes that have taken place during a rock alteration of any kind. The diagram is made up of a number of horizontal lines, which are subdivided by vertical lines according to any convenient method. The dia-

[1] Mead, W. J., Some geologic short cuts; Econ. Geol. 7, 1912, p. 136.

gram figured, which has been contrived by Mead, is so divided that a finite line represents any quantity up to infinity. One of the horizontal lines is allotted to each of the component oxides of the rock. The position of the point on each line, which represents the change of that oxide during alteration, is obtained by dividing the percentage of that component in the chemical analysis of the fresh rock by its percentage in the altered rock, and multiplying the result by 100. The points so obtained on the various horizontals may then be connected by lines. The result shows at a glance the relative gains and losses during alteration, or the absolute gains and losses if any factor is known to have remained constant. Thus, if any constituent has remained constant, then all of the constituents whose points fall to the right of the known point have decreased in absolute amount, and the constituents whose points fall to the left have increased. If weight has remained constant, i.e., if 100 grams of fresh has yielded 100 grams of altered rock, then all constituents whose points lie to the right of the vertical 100-line have decreased in absolute amount, those whose points lie to the left of this line have increased. If an absolute change in weight can be determined, i.e., if 100 grams of fresh are known to have yielded 90 grams of altered rock, then the vertical line 90 is the zero line, and points to the right or left of this represent absolute losses or gains respectively. When lack of information renders it impossible to fix any point as constant, the relative gains and losses of the different constituents are all that can be determined.

	1	2	3
SiO_2	47·58	45·42	77·86
Al_2O_3	18·03	10·64	11·96
Fe_2O_3	1·10	3·03	0·21
FeO	3·34	10·22	0·32
(Fe)	(3·37)	(10·08)	(0·40)
MgO	10·88	13·82	0·29
CaO	16·92	11·84	1·92
K_2O	0·32	0·45	0·31
Na_2O	1·04	2·17	5·67
H_2O	0·60	2·20	0·60
MnO	0·06	0·08	0·02
TiO_2	0·20	0·30	0·25
P_2O_5	0·01	0·01	0·04
CO_2	....	0·03	....
	100·08	100·21	99·45

1. Fresh, rather fine-grained olivine gabbro, containing approximately 5 per cent of olivine, the remainder pyroxene and feldspar in about equal proportions.

2. Hornblendite, from one of the large zones, observed under the microscope to be composed almost wholly of fresh, granulated hornblende.

3. Aplite, a fresh specimen of medium composition, containing perhaps somewhat more than the average of ferromagnesian mineral.

Rock Alteration.

The gabbros are on the whole only slightly altered. They have, however, been affected, subsequent to consolidation, by shearing movements, juvenile solutions, and meteoric solutions. As regards the first, regional stresses have caused a certain amount of faulting, with production of wide shear zones. Granulation of the gabbro and its partial conversion into schist undoubtedly took place along these zones, but these effects have been obscured by the action of the hornblendite-forming solutions, which flowed through the fault channels depositing hornblendite. A later faulting has sheared the hornblendite with formation of much chlorite. The second type of alterative agent, the juvenile solutions, tended to convert the rock into aplite and hornblendite. As a result, swarms of veinlets of these two types penetrate the mass.

It is probable that weathering and subsequent erosion have removed at least 300 or 400 feet of rock from the top of the East Sooke mass. This is inferred from the facts that level differences of some 300 feet are found along the summit line of the peninsula, and that, with the exception of the Maguire anorthosite, none of the more acid phases several hundred feet thick characteristically occurring about the periphery of the mass is found in its interior. If this inference is correct, it is probable that a mantle of well weathered material cloaked the surface before glaciation; but glaciation has thoroughly removed any such mantle and has left the rock surfaces clean and fresh. The only positive evidence that still exists to indicate the supposed previous condition is the occasional occurrence along the shores of Sooke peninsula of vertical dyke-like bands of gabbro 5 to 10 feet in width, now completely altered to soft kaolinic material, but still preserving the original texture of the gabbro and containing unaltered nodules of it. These seem to have been formed by seepage of meteoric water along joint cracks.

Weathering since glaciation extends only a fraction of an inch from the surface in massive rock, and a few inches where jointing has allowed rain and air to penetrate more rapidly and easily. The feldspar has been partly kaolinized, the augite uralitized, the olivine converted to serpentine, and the ilmenite to leucoxene.

Some of the aplite veins have been epidotized. This is believed to be due to meteoric waters and the localization in these veins is probably due to the good channels afforded the solutions, and perhaps also to the composition and fineness of grain of the veins. The feldspars have been completely converted in some places to iron-poor varieties of epidote, such as zoisite and clinozoisite, and in places to an iron-poor pistacite. Kaolin has usually been formed at the same time, and probably also quartz, although any quartz thus formed cannot be separated from the quartz originally present. Some aplite dykes were found consisting wholly of quartz, kaolin, and epidotes, and nearly all have undergone this change to a greater or less degree.

Triple Points.

It is of interest to note the occurrence in the gabbro of two fairly definite limits, which may be termed " triple points " for want of a better name. As already described, the gabbro is not of uniform composition throughout, but includes types ranging from highly basic to extremely siliceous. This change is accompanied by a corresponding change in the composition of the feldspar from anorthite in the most basic varieties to albite in the most siliceous. In the most basic types olivine forms approximately 25 per cent of the rock, and is accompanied by pyroxene and anorthite or bytownite. The proportion of olivine becomes less and less in the rocks characterized by progressively more sodic feldspar, until it disappears altogether when the feldspar becomes $Ab_{40}An_{60}$. The point at which olivine ceases to appear is the first "triple point," so called because it apparently marks the limit of the equilibrium of olivine, pyroxene, and feldspar in an increasingly sodic series of magmas. It is true that many rocks with feldspar more calcic than $Ab_{40}An_{60}$ do not contain olivine, but this is ascribed to the removal from such rocks of the olivine crystals, by sinking, after the partial crystallization of the rocks.

The second " triple point " observed is identical or nearly so with that found by W. H. Collins in the Gowganda diabases.[1] At this point feldspar, pyroxene, hornblende or biotite, and free quartz are in equilibrium, and the feldspar has the composition $Ab_{65}An_{35}$. Rocks containing feldspar more calcic than this are composed of pyroxene and feldspar with accessory titanium and iron combined as titaniferous magnetite. Rocks with more sodic feldspar contain in addition hornblende and biotite (Collins found biotite only), with free quartz, and accessory iron and titanium take the forms of titanite and magnetite.

Emphasis may be laid on the fact that the sudden mineralogical changes at the " triple points " are not accompanied by any sudden change in chemical composition. On the contrary, all the evidence indicates that the chemical changes are gradual and smoothly progressive. Collins found a similar condition to prevail.

[1] Collins, W. H., Geol. Surv., Can., Mem. 33, 1913, p. 80.

INTERNAL STRUCTURAL RELATIONS.

Spatial and Contact Relations.

The relations between the different rocks of the mass are of two classes; general arrangement in space, and contact relations. Although both of these have been taken up to some extent, the previous statements are here recapitulated and somewhat enlarged.

In space, the olivine gabbro occupies the whole central part of the intrusive. If its upper horizons were originally of other composition, all trace of this condition, except the anorthosite remnant on the summit of mount Maguire, has been removed by erosion. Erosion has also eaten deeply into the edges of the mass locally, especially on the western and southeastern coasts, and there the olivine gabbro outcrops directly on the seashore. The augite gabbro is found over the remainder of the coast-line, occupying a position peripheral to the olivine gabbro and forming a partly removed shell around it. It is found in a narrow strip around the southwestern end of the peninsula, and as a wider band along the north coast. Anorthosite does not occur in any continuous mass, but small bodies of it are scattered throughout the strip of augite gabbro, and larger bodies at or near the contact of the olivine and augite gabbros. Thus the largest mass on mount Maguire is directly underlain by olivine gabbro, and the moderately large masses on the western coast and near Beechey head lie fairly close to the contact of the olivine and augite gabbros. The only granite mass found on Sooke peninsula occurs at the extreme southwestern tip, on Possession point, intruding the augite gabbro there; this point is supposed to be very near the original periphery of the body, as the augite gabbro here forms an extensive contact breccia with the Metchosin basalt, and such bands of contact breccia are nowhere else found to be more than 200 or 300 feet in width.

Turning now to the relations between the different rock varieties as found at their contacts, it is necessary to consider those between the different varieties of each principal rock type and also those between the different types. The varieties of olivine gabbro described on page 9, are usually found to possess gradational relationships with one another so that although the zone in which gabbro of one texture passes into gabbro of another is usually only a few inches in width, sometimes as narrow as one inch, still there is no sharp line of demarcation between them. Faintly intrusive relations are found in several places, however, and when these occur it is nearly always the common type of olivine gabbro which is intruded by the special-textured types. The relations which establish the fact of intrusion are: (1) in places, long narrow stringers of the intrusive penetrate the intruded rock; (2) very slight decrease in the size of the grain of the component minerals of the intrusive occurs near some of the contacts; (3) flow textures in the intrusive rocks are developed along many of the contacts.

The relations between the olivine and augite gabbros are of much the same character. At several places, as on Bentinck island and the western end of Sooke peninsula, the augite gabbro is clearly equivalent in age to the olivine gabbro, as it merges into the olivine gabbro by gradual increase of olivine. Furthermore, it is interbanded with the olivine gabbro to form a primary gneiss. At several other points, notably at the southwestern corner of the peninsula and on Race rocks, the augite gabbro is distinctly later than the olivine gabbro, since it has intruded it in the manner described, and has broken off fragments which are now included in the augite gabbro. At two points, however, in the olivine gabbro area around Beechey head, these relations are exactly reversed, and similar phenomena show the augite gabbro to be intruded by the olivine gabbro.

The anorthosites possess similar relations to both olivine and augite gabbros. The gradational relations may best be seen on mount Maguire, where the fairly pure anorthosite merges in places into true gabbro by increase in the olivine-augite content. The same gradational relation is found along the edges of the large anorthosite masses on the south and west coasts, as well as along those of the small masses scattered through the augite gabbro. In the latter places the gradation is abrupt, whereas on mount Maguire the changes are much less so. In two places, near Beechey head, the anorthosite was seen definitely to intrude the olivine gabbro, in the form of well-defined dykes.

The granite on Possession point is distinctly intrusive into the augite gabbro, and forms an extensive contact breccia with it. However, Clapp found that in other bodies of the Sooke gabbro the granite portion is clearly gradational into the underlying gabbro. It is assumed, therefore, that the granite of the East Sooke intrusive also once possessed a gradational relation to the basic rocks, and that this relation was obliterated by movements which, as will be shown, took place before solidification, as the gradational relations of the gabbros to each other were partly obliterated.

The following quotation from a recent report by Clapp[1] makes clearer the relations of the granite and gabbro as found by him in the other masses of the Sooke map-area:

" At several places, in fact along all of the exposed contacts between the two, the gabbro, which greatly predominates, and the granite may be seen to grade into one another within a distance of one to three feet. At most places the two rocks maintain their normal character to the narrow transitional zone, though usually the gabbro is more feldspathic near the transitional zone than is normal elsewhere. In a few places, as to the southeast of Empress mountain, the gabbro is fine-grained and porphyritic near the transition, and even the granite is fine-grained. In the vicinity of Empress mountain the granite clearly overlies the gabbro, and grades abruptly downward into it. . . . . . . The granite forms two or three small knolls about 100 feet high surmounting the gabbro ridge; and a mile to the southeast of the summit of Empress mountain the granite occurs at the top of the intrusive stock, forming a zone or layer 100 feet or more in thickness capping the gabbro and immediately underlying the apparently flat roof of Metchosin volcanics . . . . At several places the granite forms irregular masses, many of

[1] Clapp, C. H., Geol. Surv., Can., Mem. 96, p. 298.

them too small to map, partly or entirely surrounded by the gabbro, and in some places not situated in any definite position with regard to the gabbro. Most of the granite masses are, however, situated near the periphery of the gabbro stocks, and the two small stocks occurring along the boundary of the Sooke and Duncan map-areas are composed entirely of granite. In addition, it should be noted that the granite facies is largely confined to the smaller, less eroded stocks, and is virtually absent in the larger and more eroded, like those of East Sooke and Rocky point."

JOINTING AND FAULTING.

The dynamic movements affecting the rocks have been numerous but not large. At least eight periods can be recognized. The first, already described, occurred after partial crystallization had taken place, and brought about the internal relations indicated in the previous section. The second, third, and fourth preceded the intrusion of the three types of dykes. They evidently resulted in formation of fissures into which the dykes were intruded, and were jointing rather than faulting movements, as little or no displacement along them has been detected. In time, the movements resulting in the intrusion of the non-porphyritic gabbroid dykes and the granitic dykes evidently occurred after the solidification of the gabbroid differentiate of the magma, and before that of the granitic differentiate: the movements resulting in the intrusion of the porphyritic gabbroid dykes occurred after the solidification of the granitic differentiate. The fifth movement appears to have resulted in the formation of large faults, with wide shear zones, and accompanying joints. Although wholly inferred, this movement, especially the formation of the wide shear zones, is necessary to explain satisfactorily how it was possible for the hornblendizing solutions which escaped at this time to convert bands of gabbro up to 250 feet in width into hornblendite, when the influence of the solutions when they rose through a joint crack does not appear to have extended more than 6 or 8 inches on each side of it.

Deposition from the hornblendizing solutions apparently sealed most of the joint and fault fissures resulting from the fifth movement, so that it was not until the sixth movement, which produced new joints and small fissures cutting the old, that the escape of the aplitizing solution took place. The seventh movement resulted in further faulting. No new fault planes were produced, but the stresses were relieved by slip along the fault zones of the fifth movement, with consequent brecciation of the hornblendite which filled them. The eighth movement resulted in further jointing. In addition, some later movements probably occurred, as two or three sets of joints cut the aplite veins and each other; but as it is difficult to distinguish between the different sets, the actual number of movements producing them is unknown.

In spite of the large number of observations of strike and dip of the various joint, vein, and dyke systems, no regularity could be determined, even among those systems which belong rather definitely to a single set. It is possible that a regularity of arrangement might be established by a more intensive study, which might show that much of the jointing has been due to compressional forces; on the other hand, it is probable that many of them are tension joints, formed by the strains set up during the cooling of the mass, and without regularity of arrangement. A somewhat greater regularity is found in the faults. Their strikes vary considerably, but in general fall into two sets, the one between north 10 degrees west and north 20 degrees east, the other between north 45 degrees east and north 65 degrees east. In most places the fault planes have a steep or vertical dip. The displacement in all the faults noted is nearly horizontal, as shown by the direction of the striæ on slickensided surfaces. The dip of the striæ was not observed to exceed 20 degrees, and was invariably to the southwest. The amount of the displacement is difficult to estimate, as good horizon markers are lacking, but it is probably not much over 1,000 feet even in the largest.

MINERAL DEPOSITS.

The mineral deposits of East Sooke peninsula are of two types, copper and iron deposits. The former are of much greater economic importance. They are found in the large hornblendite zones which have suffered from a second period of faulting with consequent trituration of the hornblende crystals. The universal association of the ores with the hornblendites is apt to lead to the conclusion that the same solutions which carried the ores also hornblendized the rock, but the following facts show clearly that the true sequence of formation was: (1) hornblendite; (2) fault; (3) ore deposition.

Fresh, slickensided surfaces are common in the large hornblendite zones, whereas all other textures are destroyed; hence these surfaces were formed subsequent to hornblendization.

Small, unfaulted hornblendite zones are coarse and pegmatitic in texture, and the large ones are principally made up of fine-grained hornblende, which under the microscope is seen to be brecciated material. Hence, again, faulting followed hornblendization.

Aplitic stringers cut the small, unfaulted, hornblendite zones, but none cut the large ones. Presumably such stringers once existed, but have been destroyed by faulting.

Non-faulted hornblendite zones carry no chalcopyrite, hence deposition of copper did not accompany hornblendization.

The sulphides in the ores are universally found in distinct cracks in the hornblendite, not intergrown with the hornblende; hence deposition is subsequent to and not contemporaneous with hornblendization.

The sulphides are sometimes found deposited in cracks, the walls of which are slickensided, and sometimes ore veinlets cut across slickensides. Hence ore deposition was subsequent to faulting.

As mentioned, the ores consist largely of chalcopyrite, disseminated more or less thickly in small cracks and veinlets throughout the hornblendite mass. The percentage of chalcopyrite present may vary all the way from zero up to 100 per cent; occasionally ore chutes occur consisting of dense, massive chalcopyrite. The average good ore, however, runs about 5 or 6 per cent copper. Very few other minerals of any kind are found accompanying the chalcopyrite. A little quartz feldspar, calcite, pyrite, magnetite, molybdenite, and zeolites have been observed, but the amount of these is so small as to be negligible; and restricted to the surface is a little native copper, oxidized copper minerals, and limonite. For practical purposes it may be said that the only gangue present is the hornblendite itself.

As the large shear zones in which the ores are found yield more readily to erosional influences than the hard, unaltered gabbros, they are topographically expressed by the presence of small valleys on land; and on the sea coast, where wave action is strong, as on the southwest coast, by narrow wave-eroded chasms. These chasms sometimes run in for 100 feet or more and thus form an infallible indicator of the presence of these zones. The valleys on land, however, have been filled in with soil, so that they are now only shallow depressions, difficult or impossible to trace in the present uncleared condition of the country.

The shear zones in which the ores are found are strong and persistent, and can usually be followed for several hundred feet. The largest, that exposed on the Margaret, Copper King, and Eureka claims, is traceable for at least 4,500 feet. The strike, as described under "Faulting," page 25, varies greatly between the different zones, but there are two principal sets of shear zones, one having strikes between north 10 degrees west and north 20 degrees east, the other between north 45 degrees east and north 65 degrees east. They vary in width from a few feet to one which is at least 250 feet wide. Their size and persistence render these deposits of considerable prospective value, and make it probable that they will continue to carry good values to considerable depths. There is, however, no reason to believe that they will increase in value with depth. They will more probably decrease gradually in value, probably with gradual increase of the proportion of pyrite. Native copper, which is frequently found in small amount at the surface, is due to surface alteration only, and cannot be expected beyond depths of a few feet.

A second type of mineral deposit, very subordinate both as regards quantity and value, is the magnetite-pyrrhotite deposits. Under the course of differentiation as previously outlined, such deposits might be formed at two periods in the history of consolidation of the gabbro. They might have resulted from the early separation and aggregation of iron minerals from the body of the gabbro magma, as at Sudbury, and thus in age antedate the consolidation of nearly all its phases; or they might have been formed in the last stages of differentiation at the time of the formation of the hornblendite veins, had the waters that formed these been laden with excess of iron. That these waters did carry iron in excess of that required for the conversion of the rock into hornblendite is shown by the almost universal presence, in the middle of the small hornblendite veinlets, of strings of magnetite and pyrrhotite grains.

One of the two deposits observed on the peninsula belongs without doubt to the second type, as it is found in a large shear zone, in the form of lenses, greatly cracked and cut by the later depositions of chalcopyrite. This is the deposit at Iron mountain, section 79. Here the only gangue mineral is hornblende, in bladed forms and granulated, and the metallic minerals are magnetite and pyrrhotite. The pyrrhotite is found in fairly large, comparatively pure, masses. The other body is found on section 83; it was not examined by the writer.

These massive deposits are too low grade in copper to be even of prospective value. They are rich in the valueless metallic minerals, and it would be difficult and expensive to separate the chalcopyrite from them. The deposits have been exploited for iron as well as copper, but the sulphur is too high for the deposit to be a possible source of iron with the present conditions existing in the iron industry of this continent. It is possible that at some future time they may have some value as a source of sulphur for the manufacture of sulphuric acid. Their chief value has been as an iron flux in copper smelting.

THEORETICAL PART.

INTRODUCTORY STATEMENT.

The facts detailed in the preceding pages have shown that the Sooke intrusives include a large number of different petrographic types that fall naturally into a series of which, although the end members are widely different, the proximate members differ but slightly. The writer will endeavour to prove that these differences are due to the process of differentiation acting on an originally homogeneous magma whose composition was probably that of a rather basic basalt. The different rock types present certain irregularities, previously detailed, of distribution, shape, and inter-relations with one another; it will be shown that the most likely explanation of these irregularities is the occurrence of movement and disturbance within the masses prior to their consolidation. It is possible that the movements may have been those which accompanied the intrusion of the masses, in which case the differentiation must have taken place at greater depths; but the bulk of the evidence seems to indicate that they were not so profound as this would imply, and that the actual sequence of events was, intrusion, differentiation, and movement. The method by which the differentiation appears to have taken place is that of partial crystallization and sinking of crystals, aided in the later stages by the regional movements, which strained off or squeezed out the mother liquor from partly crystallized material. Bowen[1] has recently shown that such an explanation of differentiation appears the only adequate and possible one; and the facts observed in the study of the Sooke intrusives bear out his theory. The records of the final stage of differentiation, the period of exhalation of aqueo-igneous solutions, are here unusually complete, for there have been two types of veins formed by these solutions, a basic and an aplitic, instead of only the usual aplitic veins. Unfortunately, owing to the smallness of the intrusive mass, cooling and consolidation overtook and ended the differentiative processes before their work was complete.

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[1] Bowen, N. L., Jour. of Geol., supplement to vol. 23, 1915.

PROOF OF DIFFERENTIATION.

The following facts, which have been already taken up in detail, indicate that the various rock types have been derived from a common magma by differentiation:

The principal types occupy definite positions in space, the most basic at the centre, the most siliceous at the periphery. In undisturbed masses, such as the Empress Mountain body, the siliceous part lies at the top.

The different types and sub-varieties grade into one another at their contacts, where disturbance during consolidation has been small or lacking. Where disturbance has been great, the more acid types intrude the more basic.

Although the end members of the series are of widely differing chemical composition, the proximate members differ only slightly from one another. The mineralogical composition shows a similar gradation, except at two "triple points," where there are sudden changes accompanying the appearance of a new mineral or the disappearance of one already present.

COMPOSITION OF THE ORIGINAL MAGMA.

At present, olivine gabbro occupies approximately 90 per cent of the exposed area of the East Sooke intrusive, and augite gabbro practically all of the remainder; the relative area of anorthosite and granite exposed is very small. The proportion of granite was formerly probably larger, as on account of its peripheral position it was the first to be exposed to erosion; but from the examination of the Empress Mountain and other stocks, and from the results already quoted from Collins and Wright it seems probable that it never formed more than 10 to 15 per cent of the whole. The conclusion seems justified, therefore, that the magma was originally basaltic, and not far different in composition from the normal olivine gabbro.

This inference is strengthened by a consideration of the relations of the Sooke gabbro to the Metchosin basalts. The composition of the basalt is identical with that of the gabbro; in places olivine is present, in other places absent. The intrusions of the gabbro are confined to the same area as the extrusions of basalt. The time interval between the two periods of vulcanism was comparatively short. These facts suggest strongly that both rocks were ejected from the same underlying reservoir, the basalt representing the primary extrusive phase of igneous activity, the gabbro the secondary, intrusive phase. Under this hypothesis the composition of the Metchosin basalt represents that of the original magma, less such volatile constituents as were lost during cooling.

PROOF OF MOVEMENT PRIOR TO CONSOLIDATION.

The occurrence of the gneissic structures and textures already described indicates conclusively that movement took place prior to consolidation, but after the mass had begun to get rather viscous, partly crystalline, and perhaps in parts wholly solid. The gneissic textures could not have been produced after consolidation, as movement then would have resulted in granulation of previously formed crystals and the production of the secondary minerals characteristic of dynamic metamorphism. The occurrence of gabbros of widely differing compositions in long, narrow, gneissic bands, separated from each other by sharp gradations, indicates that when these were formed the gabbros were liquid enough to flow, and to be brought into contact with one another without exhibiting intrusive phenomena, yet sufficiently viscous to prevent intermixing. The occurrence in some bands of acicular and lath-like pyroxenes, all arranged with their long axes parallel, indicates that crystallization had at least commenced, although the crystals need not have attained their present size when they were thus oriented. The occurrence of flow textures in one variety at its contact with another indicates that that other must have been very viscous, if not solid. Finally, the generally chaotic condition in which the various varieties are arranged is also suggestive of movement, although it may also be due, partly or wholly, to the freezing of the magma while differentiation was still incomplete.

TIME OF MOVEMENT.

It has been shown that the olivine and augite gabbros were rendered gneissic in places, particularly in the peripheral parts of the mass, and were otherwise variously affected by the regional movement described in the preceding section. The granites were not rendered gneissic, but were forced into intrusive relations with the more basic types. It is evident, therefore, that the movement occurred after a fairly complete separation of the magma by differentiation had taken place, after the basic types had become very viscous and in some places solid, and before the granitic differentiate had begun to lose its complete fluidity.

TIME OF DIFFERENTIATION RELATIVE TO THAT OF INTRUSION.

It has been shown that the differentiation of the Sooke intrusive preceded a movement that affected the mass prior to its consolidation. It remains to consider whether this movement was that which accompanied the intrusion of the gabbro to its present position, or was of later date; in other words, whether the differentiation went on in situ, or took place previous to intrusion in some underlying magma reservoir. The writer is of the opinion that the mass was intruded to its present position before differentiation took place, as the results of movement do not appear to have been sufficiently profound to sustain the hypothesis of intrusion after differentiation. In support of this conclusion the following evidence is adduced:

The main mass has been shown to have been liquid at the time of movement. It seems unlikely, if differentiation took place before intrusion, that a large, forward movement would have ended in the present spatial arrangement of acid differentiates on the periphery, basic ones in the centre. More likely remixing would have occurred.

The formation of the separate species by differentiative processes which took place before movement began must have involved much crystallization of olivine, pyroxene, and probably also bytownite. It has already been shown from field evidence (page 31) that crystallization certainly had at least begun. It seems probable that any large advance of the magma after this had occurred would have caused crushing and brecciation of these already-formed crystals. This effect would be most evident in the more basic varieties of olivine gabbro. However, nothing of the sort has been observed.

It has already been shown on field evidence that the 2 or 3 per cent of the magma which forms the gneissic phases, was in a very viscous condition when movement took place. Nothing is known as to whether the remainder was viscous or fluid. Assuming a general advance of the whole magma after differentiation, let us consider both possibilities.

If the greater part of the magma was fluid, the rest viscous, a general advance of the whole magma would almost certainly result in the complete remixing of these fluid portions and the viscous parts would be rendered gneissic; so that the present condition would be that of a matrix of uniform composition surrounding patches of gneissic differentiates. This is not the case.

If the whole or greater part of the magma was in a viscous condition at the time of a general advance, then the whole or greater part would have been rendered gneissic. This is also not the case.

It seems clear, therefore, that the movement which occurred after differentiation had reached its close, or nearly so, could not have been that through which the magma attained its present position; so that differentiation went on in situ.

METHOD OF DIFFERENTIATION.

N. L. Bowen has shown in a recent paper[1] that only one of the different methods suggested in the past appears entirely competent to effect the differentiation of an igneous magma; this is the process of crystallization, with separation of crystals and liquid by gravitative influence and zoning, aided sometimes in the later stages by the compressive action of regional movements. The facts observed by the writer which tend to prove Bowen's contention will be taken up in detail, but may first be summarized as follows:

(1) Spatial relations, imperfect as they are, show that the main differentiative processes have been controlled by gravitation influence.

[1] Bowen, N. L., op. cit.

(2) The proportional relations of the different minerals in the various rock types show that these gravitative relations must have been effective after crystallization, not before.

(3) Changes occurring in the composition of the separate minerals, in so far as these can be determined, follow the course prescribed by the theory.

(4) Certain special textures and structures can be most easily and naturally explained by this theory.

Spatial Relations.

These have already been fully described, and it need only be added that the arrangement found follows the order of the specific gravity of the rocks, and hence indicates gravity as the controlling factor of differentiation.

Proportional Relations of Minerals.

One of the most striking characteristics of these rocks that first appears to the investigator is the remarkable uniformity of composition exhibited by the component minerals, which goes hand in hand with the widest variation in their relative proportions. This variation in the proportions of the constituent minerals (see page 35) can only be explained by some hypothesis which involves a purely mechanical means for their partial or complete separation from each other during or after crystallization, and makes the final location of the separated crystals largely fortuitous. The variations are too large, too rapid, too irregular and arbitrary to admit of any other explanation. The only theory of differentiation at hand which postulates such a mechanical separation is that emphasized by Bowen, that gravitative influence causes the sinking of crystals as they form and their consequent removal from their mother liquor. The distance to which they sank would be purely fortuitous, depending on the rate of sinking and the length of time their movement continued, both of which factors are dependent on the change of viscosity of the magma during cooling.

Changes in the Composition of the Constituent Minerals.

The investigators of the geophysical laboratory have shown[1] that in the crystallization of a gabbroid magma when crystals are allowed to sink as they form, the first step is the separation of olivine. Much of this sinks away from its mother liquor, so that possibilities of its further reaction are lost; but for what remains there will be a tendency to resorption when the separation of pyroxene later begins. As pyroxene forms, it changes in composition, and, in the case of a lime-magnesia pyroxene poor in iron, becomes gradually more calcic. Feldspar commences its crystallization at nearly the same time as pyroxene, and its composition gradually changes to more and more sodic. While these changes are going on, the liquid part of the magma is being enriched in silica, together with water and other volatile constituents. After a time the volatile constituents attain a concentration sufficient to cause an appreciable breaking down of the polysilicate molecules of the alkalis and the metasilicates of iron and magnesia into orthosilicates, with liberation of silica. The result is the still further enrichment of the liquid in silica, which presently begins to separate as quartz, whereas the ferromagnesian elements tend first to form hornblende and then, as the influence of water and the other volatile constituents continues to increase, biotite.

The observed changes in the constituent minerals of the Sooke gabbro follow the course outlined very closely, in so far as microscopic observation indicates. The variation of the feldspar is the most accurately determinable. In every hand specimen such variation is to be found; if the majority of the cleavage flakes indicate an average composition of Ab_mAn_n, where $m+n=100$, there are always a number present both more calcic and more sodic; these usually vary from $Ab_{m-5}An_{n+5}$ to $Ab_{m+5}An_{n-5}$, but occasionally the variations are greater than this, especially in the coarser-grained rocks. In some of the latter, zonary banding is observable under the microscope, and the outer bands are more sodic than the inner. Taking the series

[1] Anderson, O., Am. Jour. Sc., vol. xxxix, 1915, p. 407.
Bowen, N. L., Jour. Geol., Supplement to vol. xxiii, No. 8, 1915.

as a whole, although the major number of the specimens examined carry bytownite, still enough are found to make clear the tendency of the feldspar to become more and more sodic. Out of thirty-seven sections of olivine gabbro examined, six, or 16 per cent, contained feldspar whose composition varied from $Ab_{30}An_{70}$ to $Ab_{40}An_{60}$; and in thirty-three sections of augite gabbro, thirteen, or 40 per cent, carried feldspar between $Ab_{30}An_{70}$ and $Ab_{65}An_{35}$. That these sodic feldspars are really products of a later crystallization than the more basic is shown by the facts: that they are found in the outer bands of zoned crystals where these occur; that the augite gabbro, already proved to be a differentiate of the olivine gabbro and slightly later than it in crystallizing, contains a larger proportion of types carrying the more sodic feldspars; that the augite gabbro carries feldspars much more sodic than the olivine gabbro; and that the granite, proved a still later differentiate, is characterized by feldspars more sodic still.

The possible changes in the composition of the pyroxene could not be determined satisfactorily with the microscope. As for the olivine, most of the crystals show partial resorption. The mineralogical changes accompanying the appearance of quartz in the rocks have been described, and, like those of the feldspars and the olivine, follow exactly the lines indicated by the investigators of the geophysical laboratory. These facts indicate that as crystallization proceeded some agency continuously removed the crystals from the liquid magma. Preceding sections have shown that the agent must have been gravitation.

Special Textures and Structures.

The structure of the anorthosites may be specially cited as most easily explicable by the hypothesis already given. As previously mentioned, they are found as a rule in small isolated masses, a foot or so in diameter. These masses are usually coarsely crystalline, and contain very little admixture of the other rock minerals. It is difficult to account for such occurrences, except by the theory that, as feldspar crystals separated from the magma, they were segregated from the olivine and pyroxene crystals forming at the same time by the more rapid sinking of the latter, and, as they themselves slowly sank, they became aggregated together into small masses. Further sinking would probably have resulted in aggregation into larger masses, and two or three such masses are found; but for the most part the process was brought to an end by the increasing viscosity of the cooling magma.

Bowen's hypothesis also explains easily the formation of the rounded bodies of very coarsely crystalline "pegmatite" described on page 7. They may be supposed to represent large, loose masses of earlier-formed crystals, which have been consolidated by a movement of the magma, with squeezing off of the interstitial liquor.

RATE OF COOLING OF THE INTRUSIVE.

Bowen has shown that by internal evidence, chiefly the zonary banding of mix-crystal minerals such as feldspars, an approximate estimate may be made of the rate at which a magma has cooled and whether or not it underwent much supercooling before crystallization commenced. A very rapid loss of heat is apt to result in great undercooling of the liquid mass before crystallization commences; crystallization once initiated, an almost instantaneous separating of mineral takes place sufficient to bring the liquid once more into stable equilibrium with the solid phase. The whole amount of each mineral so separating will have the same composition. Very slow cooling of the liquid magma, with sinking of crystals prevented, would favour resorption of the earlier-formed crystals and thus produce a similar rock composed of minerals of uniform composition. Such a condition, however, is almost impossible to attain in nature. An intermediate rate of cooling produces zoning in the mix-crystals present, there being a special rate which will produce maximal zoning. The feldspars seem to be particularly liable to zoning, probably because on account of their low specific gravity they sink very slowly through the magma and hence are not so apt to be removed from the scene of their formation before outer layers can be deposited on them.

Applying these criteria to the East Sooke gabbro, it is found that although the feldspars in every hand specimen exhibit variations in composition, nevertheless in most of the rocks they are far from exhibiting maximal zoning. The feldspars of only a few of the coarse pegmatitic varieties are noticeably zoned. Hence it must be concluded that considerable undercooling took place, in spite of the fact that the cooling of such a large plutonic mass was almost certainly fairly slow. In support of this conclusion there might also be cited the uniform composition of all of the minerals throughout a large part of the gabbro. Furthermore, the occurrence of poikilitic textures in some of the rocks indicates a very rapid growth of the pyroxene crystals once crystallization was initiated. The rather imperfect segregation of the different minerals in the more basic rocks, as evidenced in the lack of occurrence of highly basic types such as pyroxenite, dunite, and picrite, and the incomplete segregation of the anorthosites, also points to a crystallization deferred until increasing viscosity was almost able to prevent the downward movement of crystals. The fact that so much differentiation actually did take place, in spite of the relative brevity of the period between the commencement of crystallization and the time when viscosity ended the downward movement of crystals, throws an interesting light on the speed with which sinking, once initiated, may go on.

FINAL STAGES OF DIFFERENTIATION.

During the final stages of the differentiation of the Sooke magma the hornblendite and aplite veins were formed. The processes of deposition and the behaviour of the components of the solution have been so different from that displayed during the crystallization of the original magma as to be worthy of separate detailed description. The mineralogy of the veins, their connexion with the gabbro mass, and their metamorphic effect on the gabbro have been detailed on pages 12-16 and shown by analyses on page 18, and the results of these analyses have been platted graphically in Figure 1.

General Discussion of Figure 1.

The mode of construction and interpretation of Figure 1 have already been described, and it has been shown that to determine absolute gains and losses during an alteration the weight, the volume, or the amount of some one constituent must be known to have remained constant, or, if not constant, the extent of its change must be known.

In the present case no one constituent can be assumed to have remained constant, as all were probably very soluble in the hot solutions. If alumina, the most insoluble oxide, were sup-

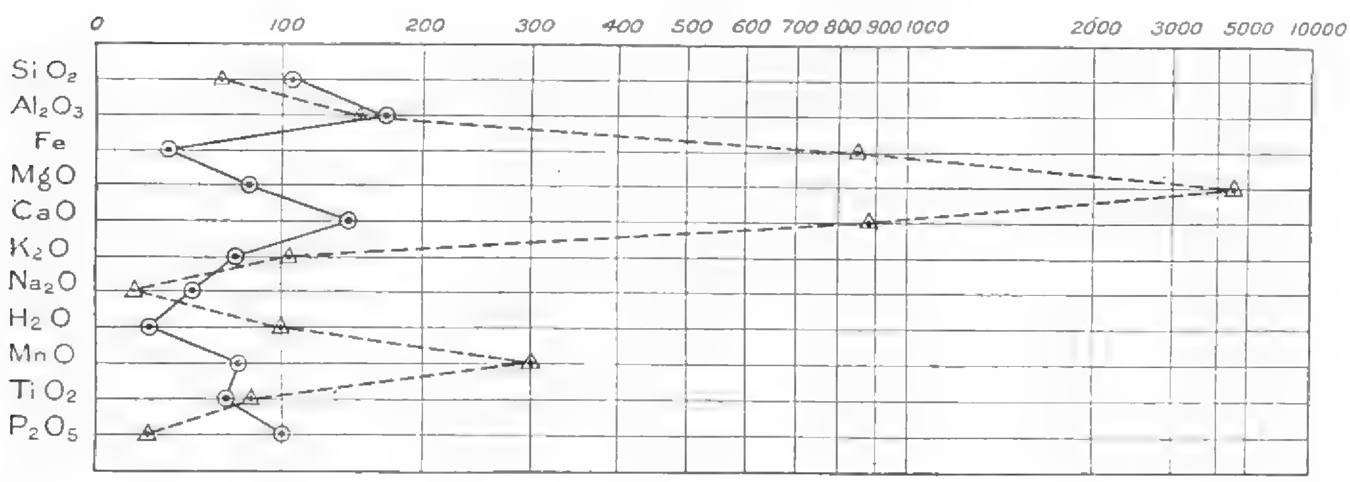

Figure 1. Diagram illustrating hornblendization and aplitization. The hornblendic alteration is indicated by the solid line, the aplitic alteration by the broken line.

posed constant throughout, the curves show that a large increase both in weight and volume must have taken place, of which there is no field evidence. The aplite is approximately 10 to 15 per cent lighter, the hornblendite about the same amount heavier, volume for volume, than the gabbro. If, therefore, the weight remained constant throughout the alteration, it must have been accompanied in the aplite by increase, in the hornblendite by decrease of volume. There was no evidence observed in the field that either occurred. The most probable assumption appears to be that volume remained constant or nearly so. If so, the zero point for the hornblendite curve would lie between the vertical lines 110-115, for the aplite curve between verticals 85-90.

Under this assumption, and leaving out of consideration the minor components of the solutions, such as K_2O, MnO, TiO_2, and P_2O_5, which altogether make up less than 1 per cent of any of the rocks, it is seen that the hornblendite alteration resulted in slight increase of silica, large increase of iron, magnesia, soda, and water, with loss of lime and alumina. In the aplitic alteration a somewhat larger increase in silica and soda took place, whereas water was slightly lost, alumina more so, and lime, iron, and magnesia almost completely removed. It may also be seen from Figure 1 that in the main these conclusions are correct, whether the hypothesis of constancy of volume be accepted or not, as most points are so far to the right or left of the assumed zero vertical that, in order to alter their significance materially, quite inadmissible assumptions as to weight and volume changes would have to be made. Thus, for instance, to assume that magnesia had not been added during the hornblendizing alteration, would be equivalent to assuming that the hornblendite possesses approximately 30 per cent of pore space, which is contradicted by field and microscopic evidence.

Composition of Solutions.

The hornblendizing solutions reacted with the gabbros very readily and rapidly, judging from the wide bands of altered rock which have resulted from the percolation of solutions along very narrow joint cracks; and in no case was it found that further alteration took place after the rock was once thoroughly altered to hornblende, although in some cases additional magnetite was deposited. It is reasonable to conclude, therefore, that the hornblende was in equilibrium with the solutions when the alteration was complete, except that the solutions were apt to be still supersaturated with iron. Analysis No. 2, therefore, an example of thorough alteration so far as the microscope can show, represents the composition of the solid in equilibrium with the liquid which produced the alteration. Such an equilibrium implies the presence in the solution of all the component oxides indicated in the analysis, though not necessarily in the same proportions as in the hornblendite; in fact, the solution must have been saturated with the compounds in which these oxides existed in solution, under the existing conditions of temperature and pressure. The solutions were not, however, in equilibrium with the gabbro, hence the minerals of the gabbro were metasomatically replaced. In this way the gabbro became enriched, particularly with iron, also with magnesia soda, and probably to a small extent with silica: and became impoverished in alumina and lime.

The aplitic solutions did not react so readily with the gabbro as did the hornblendizing solutions, and although the tendencies of the alteration can be observed in many places, it might be difficult to find one in which alteration has been carried to its limit, and the gabbro completely transformed to pure aplite. The evidence as to the composition of solutions drawn from a consideration of the composition of the solid with which they are in equilibrium is not, therefore, available; but fortunately this can be obtained directly, as much aplite is present in the form of fissure fillings. Analysis 3 represents one of these, an average aplite vein, selected because it represents at once the solid that was in equilibrium with an aplitic solution and the result of an ideally complete aplitic alteration. As detailed in the previous paragraph, the presence of each oxide in the aplite indicates that it must have been present in the solution. The proportions were different, however, from those of the hornblendizing solutions, for whereas the latter added to the gabbro magnesia, iron, and soda, with some silica, and removed only alumina and some lime, the former added silica and soda in larger amounts, and almost completely removed iron, magnesia, and lime. The hornblendizing solutions must have been more concentrated than the aplitizing, at least in iron, lime, and magnesia and perhaps in all constituents.

Relative Physical Conditions of Vein-Deposition.

As regards the relative physical conditions of deposition of the two types of veins, it is probable that the aplites were deposited from cooler, more dilute solutions than were the hornblendites. The aplites were of later formation, for before the deposition of the aplites began the deposition of the hornblendites was completed and the gabbro had undergone a period of jointing. How long this period was there is no means of ascertaining, but, long or short, the cooling intrusive must have lost heat during it, and the outflowing solutions must have been correspondingly cooler. Again, it has just been shown that the aplitizing solutions were less concentrated in magnesia, lime, and iron than the hornblendizing solutions, and although concentration may depend on several factors, it is pre-eminently a function of temperature; hence the conclusion is fair that the aplitizing solutions were the cooler. In the third place, it has been shown by Bowen, in the paper already cited, that the presence of biotite in a rock is indicative of high concentration of volatile constituents, of which the chief is water; hornblende indicates lower concentration of water, augite, a magma poor in water. The ferromagnesian mineral crystallizing in the aplite veins is biotite, that in equilibrium with the hornblendizing solutions was hornblende. If Bowen's conclusions are correct, therefore, the aplitizing solutions must have been higher in water than the hornblendizing. The increased concentration of water could only have been attained by the crystallization from solution of part of the contained solids, a function of decreasing temperature mainly; hence again the aplitizing solutions must have been the cooler of the two.

Summary of Facts Known Regarding the Hornblendizing and Aplitizing Solutions.

It has been shown that both the hornblendites and the aplites are deposits from aqueo-igneous solutions exhaled from the Sooke gabbro during its final stages of cooling. Both types of solutions escaped through joint and fault fissures, altering the rocks as they passed. Both types contained all the component rock oxides, although in different proportions; the hornblendizing solutions were the more concentrated, perhaps in all constituents, but certainly at least, in magnesia, lime, and iron. The aplitizing solutions were cooler, and contained a larger proportion of water. Corresponding to these differences there was a marked difference in the metamorphic effects of the two solutions. The hornblendizing solutions deposited magnesia and iron, whereas the aplitic solutions removed these constituents. They removed lime to a small extent, but the aplitic solutions removed much more. They added a little silica, but the aplitic solutions added much more, and, as the progressively greater silica content toward the centre of the aplite veins shows, the proportion deposited grew progressively greater, and the proportion of lime-iron-magnesia mineral progressively less. In their effects on alumina and soda, there was less difference between the two solutions. Each removed very nearly the same proportion of alumina, and added nearly the same proportion of soda, though in the latter case the aplitic solutions were slightly more effective. The hornblendizing solutions were the more active metasomatic agents, and altered the larger volumes of rock.

Origin and History of the Solutions.

In the case of a gradually cooling body of magma there appears to be no reason to suppose that any sudden discontinuity should occur in the processes taking place—in this case in the emission of aqueo-igneous solutions. The supposition of gradational changes in composition, accompanying the gradual decrease of temperature that goes on, seems to be more reasonable. Under this hypothesis the hornblendizing and aplitizing solutions appear only as two phases of one continuous process, the exhalation of volatile constituents from the magma, their differences in composition due merely to the natural changes of temperature, and other physical conditions, which had taken place in the interval between their emission. Such a hypothesis, though incapable of direct proof, groups all the observed facts together naturally, and affords a satisfactory explanation of the complementary nature of the effects of the two types of solutions, as shown on Figure 1.

Under this hypothesis the final aqueous exhalations of the magma carried in solution varying amounts of all the different component oxides of the gabbro—silica, alumina, iron, magnesia, lime, and soda particularly. As these solutions rose and cooled, the first reaction, as will be shown, was probably the deposition of lime. As cooling continued, the iron-magnesia compounds reached their limit of solubility, and through reactions with the wall rock the hornblendite veins were formed. The crystallization of the components which entered the hornblendite left the solutions relatively enriched in water and silica, and to a less extent in soda. During this period of hornblendite formation, the remainder of the solutions probably escaped beyond the limit of the intrusive, as they left no record of their presence. As the gabbro mass continued to cool, the precipitation of lime, magnesia, and iron went on at progressively greater depths, until the solutions, as they passed the surface of the mass, were sufficiently cooled and enriched in silica, soda, and water, to precipitate the constituents of aplite. With progressive cooling, the soda precipitated in smaller and smaller proportion, so that the central part of the aplite veins is largely or wholly quartz.

Conditions Governing Escape of Solutions.

The previous description indicates the probable course of events had the exhalation and escape of the solutions from the cooling gabbro been a continuous process. But it was not a continuous process, for although the formation and segregation of the solutions themselves undoubtedly went on without cessation at some point or points within the borders of the intrusive as it gradually cooled and crystallized, the escape of these solutions was controlled by the fortuitous formation of the necessary channels by jointing or faulting. Hence the composition of the veins as they are actually found simply gives us a clue to the composition of these magmatic waters at two periods. Had jointing taken place at other periods, veins of quite different composition might have resulted. Earlier jointing would probably have yielded veins whose mineralogy approached that of contact metamorphic deposits; later jointing, veins of pure quartz. The solutions which deposited the copper ores in this stock may have been a later phase of these same magmatic waters, although on account of the poverty of minerals other than chalcopyrite in the copper deposits definite information on this point is so far unobtainable.

It seems probable that this control of the escape of solutions by jointing and faulting may be the explanation of the usual absence of hornblendite types among the igneous veins formed as the last products of differentiation of other magmas. If jointing was deferred until the magma had cooled to a point where the solutions could not carry lime, iron, and magnesia, except in small quantities, nothing but aplitic veins would be formed. This might have been the case in the mass under discussion, had not regional faulting fissured the rocks soon after their consolidation.

Additional Considerations and Conclusions.

Behaviour of Lime in the Solution. From the analyses and Figure 1 it may be inferred that the concentration of lime in the hornblendizing solutions was higher than in the aplitizing. It has also been shown that the former were hotter than the latter. Projecting this temperature-concentration curve for lime, the conclusion may be drawn that still hotter, earlier solutions than any of those which have left their record here might carry lime in still larger proportions, and deposit it in some form at an earlier date. Such deposition of lime would then have ended before that of hornblende began.

Behaviour of Alumina. As shown on Figure 1, there was some loss of alumina from the wall rocks during alteration by both types of solutions. On the hypothesis of constant volume, previously shown to be the most probable, the proportion of alumina removed is almost identical in both. It seems probable, therefore, that the solubility of alumina in these juvenile solutions, at whatever temperature, was never great enough to satisfy the other bases present for the formation of alumino-silicates, so that constant additions to the supply had to be made by drawing on the wall rocks.

SUMMARY.

The Sooke gabbro is found throughout the Sooke map-area, southern Vancouver island, as a number of masses of varying size intrusive into the Metchosin basalts. It is of lower Oligocene age. Its resemblances in composition to the Metchosin basalts, and the restriction of its occurrence to the areas underlain by them, strongly suggest the view that it represents the plutonic phase of the igneous cycle that began with the extrusion of the basalts in late Eocene times. The masses examined by the writer were those underlying East Sooke peninsula and Rocky point. The other gabbros of the Sooke map-area were studied by C. H. Clapp, and present certain differences which may be summarized as the results of quieter, less disturbed crystallization.

The intrusion of the gabbro seems to have taken place quietly, as it has not formed extensive shatter breccias at its contacts. Cooling then began, and evidence has been given to show that a considerable degree of undercooling probably took place before crystallization was initiated. When the crystals began to form, they coincidently began to sink through the liquid magma, on account of their greater specific gravity, and thus caused the separation of the originally homogeneous magma into several portions of differing composition, the lighter of which occupied the upper horizons. This primary differentiative process was not long continued, however, and did not result in any very perfect sorting of the various rock minerals, as it was brought to an end at an early date by the increasing viscosity of the cooling liquid. It resulted, however, in the production of four different rock types, of definitely different mineral composition; and each type groups together a series of rocks whose end members differ widely in composition, but of which any two adjacent members differ only slightly. Even the classification into four general types is a more or less arbitrary one, since, as might be expected from rocks so formed, the different types merge into one another by a gradual change in mineral composition.

The types so formed are: olivine gabbro, made up of olivine, pyroxene, and bytownite feldspar; augite gabbro, similar to the preceding but without olivine; anorthosite, consisting of bytownite feldspar either pure or containing small quantities of pyroxene with or without olivine; and granite, made up of quartz, hornblende and mica, and oligoclase. The olivine gabbro was the heaviest of the differentiates, as well as much the largest in quantity; it, therefore, occupies the central and lower parts of the mass, and covers about 90 per cent of its present exposed area. The augite gabbro occupies a peripheral position on the north and south coasts, and covers most of the remaining 10 per cent of the exposed area. The anorthosite, the only monomineralic rock formed, shows the effects of the incomplete sorting that took place, as it is found in fairly large bodies in two or three instances only, but occurs chiefly in little bodies, a foot or so in diameter, scattered throughout the augite gabbro. All of the granite that may have been formed has been removed by erosion, with the exception of one small outcrop on Possession point, on the very periphery of the intrusive.

After the formation of the various rock types had been brought to an end by the increasing viscosity of the cooling liquid, regional disturbance took place, the effects of which were of great importance. The still semi-liquid mass was churned up; but as the different phases were already too viscid to remix readily and thoroughly, more especially in the cooler, outer parts of the stock, the result was merely the partial destruction of the earlier gravitational arrangements of the rocks, the irregular interpenetration of one by masses and streams of another, and the production of gneissic bands and flow textures. It is also probable that there was a general straining off of small masses of liquid, acid differentiate, which went to swell the main body of granitic differentiate at the upper horizons. Besides replacing regular with irregular arrangements, producing gneissic textures, and assisting differentiative processes by straining off acid magma, the movements destroyed to some extent the gradational relations between the different types that had previously existed, and in some cases forced more liquid portions into intrusive relations with the more solid.

After the events described and the consolidation of the rocks now at the surface was completed, they were intruded by two series of satellitic dykes, an acid and a basic. The latter were the earlier and of much the same composition as the gabbro itself, and the acid varieties form a series varying in composition from a quartz diorite to a very siliceous granite. Then followed a period of faulting with production of large shear zones in the gabbro, accompanied by much jointing. Through the fissures and shear zones rose very hot solutions highly charged with mineral matter, which altered the rocks with which they came in contact to masses of hornblendite. Another period of jointing ensued, and through this set of fissures there again rose solutions which formed aplitic fissure and replacement veins. After these were formed, a second period of faulting took place, in which the stresses relieved themselves along the earlier-formed shear zones now filled with hornblendite, and through the brecciated and crushed hornblendites the solutions which deposited the chalcopyrite ores ascended. Finally, further minor jointing took place.

The relations of the hornblendites and aplite to each other and the main gabbro mass were studied in some detail. It was shown that these are the pegmatitic after-effects of the intrusion, the last exhalations of the cooling magma. The hypothesis is advanced that the emission of such solutions from a magma is a continuous process throughout the whole period of cooling, but that the escape of the solutions so formed is governed by the more or less accidental occurrence of movements able to joint the intrusive and thus afford channels of flow. The load of such solutions always includes all the constituents of the rock from which it has originated; although the amounts of these vary, and are dependent on the temperature of the solutions, and probably also on other conditions of which we are ignorant. The composition of the veins formed by them, and their metamorphic effects on the wall rocks, therefore, vary according to the time in their history when they were enabled to make their escape. In the case under consideration, opportunity for escape occurred at two, or possibly three, periods, owing to the frequency with which jointing and faulting movements affected the stock, and veins of different composition thereby resulted.